

Investigation of Radioactivity in PBRF Concrete

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Constructors, Inc.

For

U.S. Army Corps of Engineers
Under Contract # DACW-27-97-D-0015

August 5, 2005

Investigation of Radioactivity in PBRF Concrete

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1.0 Introduction

The current decommissioning strategy for the Plumbrook Reactor Facility (PBRF) calls for the removal of activated portions of the concrete bioshield and disposition of the activated concrete as radioactive waste. Any activated concrete remaining in place will be evaluated for residual radioactive contamination volumetrically using the subsurface structure DCGLs (NASA 2004). Previous investigations conducted at the PBRF have identified the presence of activation products in samples of concrete (and reinforcing steel, or rebar) removed from the bioshield in the vicinity of the reactor core mid-plane. The Teledyne Study (Teledyne 1987) reported Co-60 concentrations in concrete cores at distances of up to 10 inches from the Reactor Vessel wall. However, elevated gross beta activity concentrations were measured at distances up to 44 in. from the vessel wall in the vicinity of the Thermal Column.

The Draft Pre-design Investigation Report (MWH 2000) identified the bioshield aggregate as high-density “Barytes” concrete and reported about 0.5 pCi/g Ba-133 in one sample but did not report detectable Co-60 (>MDA) either in the concrete or the steel bioshield liner. The sample descriptions were insufficient to accurately identify where the bioshield samples were collected. From the two referenced studies, it can be concluded that bioshield concrete was activated in the core region at depths up to the thickness of the main bioshield annular structure (24.5 in.). Concrete in the Quad B monolith was also possibly activated in the vicinity of the Thermal Column, where the concrete shield structure extends well beyond the 24.5 in. annular structure.

A literature review was conducted to identify activation product radionuclides potentially present in the bioshield concrete and reinforcing steel (PNL 1984, PNL 1993). The radionuclides are listed in Table 1-1. The list is based on typical material composition of high-density barytes concrete containing steel reinforcing and considers the 32 year decay period since shutdown in 1973 (short-lived nuclides are not included in the table). The table also shows the applicable DCGL and principal decay emissions for each radionuclide. The DCGLs were derived for volumetrically contaminated material in subsurface structures and are reported in the PBRF Final Status Survey Plan (Attachment B, Table 5-14).

In view of the limitations of the previous bioshield core bore sampling investigations and the time elapsed, it was determined that the available information was insufficient to determine if removal of any portion of the bioshield concrete will be necessary to achieve applicable decommissioning release criteria (DCGLs). Samples that were collected as part of this investigation will be used to help make that determination.

Table 1-1 provides a basis for core bore sampling data objectives to determine the extent of activated concrete that must be removed from the bioshield. The DCGLs, along with structural constraints, serve as criteria for removal decisions. The most limiting radionuclide is Co-60, followed by Eu-152 and Eu-154, all of which are readily assayed

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by gamma spectroscopy analysis of core bores of concrete and concrete containing rebar. These gamma emitters are primarily produced by thermal neutron (n,γ) reactions with impurities and elements in the concrete and reinforcing steel. Since the bioshield walls surrounding the reactor vessel are high-density concrete (containing “baryte”, barium sulfate BaSO₄) the activation product Ba-133 is also potentially present.

Table 1-1

Screening List of Activation Product Radionuclides in Bioshield Concrete

Radionuclide	Half-Life (yrs.)	Host Material	Proposed FSSP DCGL (pCi/g)	Predominant Gamma Energies (kev)
H-3	12.3	Concrete	166	None (weak beta)
C-14	5736	Concrete	17	None (weak beta)
Fe-55	2.7	Concrete/Rebar	685	None (weak beta)
Ni-63	100	Concrete/Rebar	779	None (weak beta)
Co-60	5.3	Concrete/Rebar	3.3	1173, 1333
Ba-133	10.5	Concrete	Note (1)	81, 303, 356
Eu-152	13.3	Concrete	9.4	344, 799
Eu-154	8.8	Concrete	8.6	123, 1274, 1005

Note (1) Ba-133 was not identified as a significant constituent of concrete contamination when DCGLs were established for volumetrically contaminated building demolition material.

The need for additional concrete core bore samples in other areas of the plant was identified in Final Status Survey Functional Team discussions. Some comments were directed to specific areas where water pressure may have forced contaminants into open spaces between walls, floors and cracks in walls or floors. Additional comments were directed to the limited data available at the time the Final Status Survey Plan (FSSP) was submitted for approval by the NRC. Therefore, as requested by NASA, data from these additional samples will be used to supplement data from previous investigations at PBRF and to support a re-evaluation of radionuclide mixtures and activity ratios. These results will also be compared to radionuclide composition and activity fractions published in the FSSP.

The primary sampling objectives for the Balance of Plant core bores are to determine:

1. The depth of contaminated material in the sample regions in voids and cracks.
2. The depth of penetration of soluble radionuclides, particularly H-3 and Cs-137 into concrete that has long been exposed to contaminated water.
3. The residual contamination radionuclide mixture(s) in concrete.

Sampling was done in areas of elevated activity to provide some assurance that sufficient activity was collected to produce statistically meaningful results. Sampling in areas of

degraded surface coatings, near floor drains, embeds, seams and cracks will produce data to determine the extent of contaminant migration. Volumetric samples were collected at crack locations where residual activity was found to be significantly above background levels.

2.0 Bioshield Core Bores

The bioshield core samples were collected under Characterization Package E1000 101C4, "Containment Vessel Reactor Cavity Concrete Activation". Three core samples were taken from inside the Containment Vessel. The bores were drilled into the bioshield at the 45 degree azimuth, -18 ft. elevation, -21 ft. elevation (reactor mid-core) and the -24 ft. elevation. A fourth sample was taken from a bore drilled from the Quad C wall, toward Quad B. It extended through the wall (24 in.) and about 8 inches into the Quad B Monolith surrounding the Thermal Column. A plan view of the bioshield showing core bore locations is provided in Figure 1.

To obtain gamma assay data from the on-site lab, it was necessary to cut the solid cores into ½ in. thick pucks. Portions of the cores that did not yield intact pucks could be sent to on off-site lab for processing, as appropriate, for quantitative gamma spectroscopy analysis. Specified samples (including rebar) were also analyzed off-site for difficult to detect nuclides such as C-14, Fe-55 and Ni-63.

Although 5 core bore locations were originally identified in the survey package; no sample was obtained at the -21 ft. elevation, 225 degree azimuth).

The following briefly describes the bioshield core samples obtained:

1. Core bore # 1 was obtained on May 24, 2005 by drilling horizontally into the bioshield at the mid-plane of the Reactor Core (-21 ft. elevation). The bore was about 23 inches deep and was removed in 3 parts: 0-12 in., 12-19 in. and 19-23 in. All of these portions were in the form of loose debris and there were no portions of the core that could be cut into cylindrical pucks. Each sample was analyzed on-site and the results are listed in table 4-1. As noted in the table, those results are not quantitative but are included in this report for information. Material from the first 12 inches of the core and also from the last part of the core (19-23 in.) were sent to an off-site lab for quantitative analysis. Those results are also included in Table 4-1.
2. As noted above, no sample was obtained from location #2.
3. Core bore # 3 was obtained on May 25, 2005 by drilling horizontally into the bioshield at the -18 ft. elevation (3 ft. above the mid-plane of the reactor core). The bore was about 6 inches deep and was removed in 4 parts: surface to 1 in., 1 - 2 in., 2 - 4 in., and 4 - 6 in. The samples were in the form of loose debris and there was no intact core material that could be cut into cylindrical pucks. Each sample was analyzed on-site and the results are listed in table 4-2. As noted in the table, those results are not quantitative but are included in

this report for information. Material from the first inch of the core and also from the last part of the core (4-6 in.) was sent to an off-site facility for quantitative analysis. Those results are included in Table 4-2.

4. Core bore # 4 was obtained on May 25, 2005 by drilling horizontally into the bioshield at the -24 ft. elevation (3 ft. below the mid-plane of the reactor core). The first 1½ in. of the core was loose debris, but the rest of the core was solid and seven ½ x 3 in. pucks were obtained. There were a total of 11 samples from this core and all were analyzed on-site. Seven of the samples were counted in a standard ½ in. x 3 in. geometry. The results of those analyses are listed in Table 4-3. The first and last samples from this core were sent to an off-site lab for further analysis. Those results are included in Table 4-3.
5. Core bore #5 was obtained on May 26, 2005 from the south wall of Quad C, toward Quad B and into the Monolith around the Thermal Column in Quad B. The Monolith is also referred to as the Thermal Shield in some Project documents. The last section of this core (about 7-8 in.) was material from the Monolith. This material was of interest because of the possible presence of activation products in the Monolith in the vicinity of the Thermal Column.

3.0 Core Bores from Balance of Plant (BOP)

Core bore samples from the Balance of the Plant were collected under Characterization Package C9000 101I3, "Concrete Core Boring in Various Plant Buildings". All core bores were 3 in. diameter and, unless otherwise specified, 3 in. deep. Several cores were bored at an angle into the walls to obtain samples from the cold joints between the walls and floors to evaluate possible infiltration of radionuclides.

Other bores were drilled horizontally into walls or vertically into the floor. Attempts were made to locate areas of elevated contamination levels where cracks or deterioration of surface coatings were present. This was done to help ensure that the worst case scenarios for infiltration of contaminants into the concrete were examined.

Although twenty possible sample locations were identified in the survey package, samples were collected at only 17 of those locations. The horizontal wall sample was not taken in Quad C of the Reactor Building because samples from the wall were available from the angled core taken in that area. No sample was taken in Quad D of the Reactor Building because of asbestos containing material in the walls. Only one sample was taken in the Primary Pump House, Room number 4 because only one area in the room could be located with elevated surface contamination levels. The sample locations are listed in Table 3-1.

All cores were cut into ½ in. x 3 in. pucks if possible. Beta readings were taken on both the tops and bottoms of the pucks to obtain a profile of net Beta activity through the length of the cores. The results of these profiles are in the respective data tables in section 4.2 of this report.

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The appropriate DCGLs for evaluation of the BOP sample results are those for volumetrically contaminated material in subsurface structures. They are reported in the PBRF Final Status Survey Plan (Attachment B, Table 5-14). The relevant DCGLs from that table are in Table 3-2 of this report.

The first puck from each core sample was submitted for gamma spectroscopy analysis by the on-site lab. They were counted with the top facing the detector and also with the bottom facing the detector. Some sample locations were selected for tritium analysis based on an assessment of possible past exposure to either tritiated water or airborne tritium. Some samples were also analyzed for strontium content. The tritium and strontium analyses were performed at the off-site lab. Details about the cores obtained and the results of the various analyses performed are contained in section 4.2.

Table 3-1

Balance of Plant Core Bore Locations

Core #	Location	Date Collected
1	Reactor Building Quad A (Angled into wall/floor)	June 7, 2005
2	Reactor Building Quad C (Angled into wall/floor)	June 6, 2005
3	Reactor Building Quad A (Horizontal into wall)	June 7, 2005
4	Reactor Building Quad C (Horizontal into wall)	No sample taken
5	Reactor Building Quad B (Horizontal into wall)	June 9, 2005
6	Reactor Building Quad D (Horizontal into wall)	No sample taken
7	Reactor Building (Lily Pad)	June 15, 2005
8	Reactor Building Canal E (Horizontal into wall)	June 7, 2005
9	Reactor Building (Floor of the Pump Rm. Trench)	June 17, 2005
10	Reactor Building Canal G (Angled in wall/floor)	June 16, 2005
11	Reactor Building Canal H (Angled into wall/floor)	June 15, 2005
12	Reactor Building Canal G (Horizontal into wall)	June 16, 2005
13	Reactor Building Canal H (Horizontal into wall)	June 16, 2005
14	Primary Pump House sample # 1	No sample taken
15	Primary Pump House sample # 2	June 14, 2005
16	Waste Handling Building (Floor of – 13 ft. el.)	June 13, 2005
17	Pipe Cold Tunnel Trench	May 12, 2005
18	Cold Pipe Tunnel Floor	May 12, 2005
19	Fan House (Floor of – 12 ft. el.)	June 10, 2005
20	Hot Pipe Tunnel (Floor)	June 10, 2005

Table 3-2

Subsurface Structural DCGLs

Radionuclide	Proposed FSSP DCGL (pCi/g)
H-3	166
Co-60	3.3
Sr-90	0.6
Cs-137	2.2

4.0 Sample Results

4.1 Bioshield Activation

The following tables list the results of analyses of core bore samples from the reactor bioshield. The first column of results in each table (On-Site Analysis) is included for information. The last column in each table (Off-Site Analysis) contains quantitative data. Most of the core samples obtained from the bioshield were not solid and tended to crumble into debris when removed from the core drill bit.

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Table 4-1

Bioshield Core Bore # 1

Reactor Core Mid-Plane - 45 Degree Azimuth (-21 ft. elevation)

Sample Depth	Sample Size	Nuclide Activity (pCi/g) On-Site Analysis *		Nuclide Activity (pCi/g) Off-Site Analysis **	
0-12 inches	1.50 E+3 g	Co-60	2.50	Co-60	3.39
		Ag-108m	7.21 E-2	Ag-108m	N/A
		Cs-137	1.53 E-1	Cs-137	1.26 E-1
		Eu-152	3.92	Eu-152	1.05 E+1
				Eu-154	7.41 E-1
				Ba-133	6.57 E+1
				Tritium	<MDA
12-19 inches	2.05 E+3 g	Co-60	9.51		
		Ag-108m	2.07 E-1		
		Cs-137	1.89 E-1		
		Eu-152	1.57		
		Eu-154	1.04 E-1		
19-23 inches	1.20 E+3 g	Co-60	5.44	Co-60	2.24
		Ag-108m	2.82 E-1	Ag-108m	1.21 E-1
		Eu-152	5.35 E-1	Eu-152	4.94 E-1
		Ba-133	N/A	Ba-133	2.38
		Cs-137	N/A	Cs-137	8.62 E-2

* Most bioshield samples analyzed on-site were in a non-standard geometry. The results listed in this column are qualitative only unless otherwise indicated.

** Samples analyzed off-site were processed to produce samples that could be analyzed with a "standard" counting geometry. Results listed in this column are quantitative.

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Table 4-2

Bioshield Core Bore # 3

Three Feet Above the Reactor Core Mid-Plane - 45 degree Azimuth (-18 foot elevation)

Sample Depth	Sample Size	Nuclide Activity (pCi/g) On-Site Analysis *		Nuclide Activity (pCi/g) Off-Site Analysis **	
0-1 inch	4.55 E+2 g	Co-60	1.74 E-1	Co-60	1.18 E-1
		Cs-137	1.23 E-1	Cs-137	<MDA
		Eu-152	5.17 E-1	Eu-152	7.23 E-1
		Eu-154	2.30 E-1	Eu-154	<MDA
				Ba-133	6.37
				Tritium	< MDA
				Ni-63	3.09 E+1
1-2 inches	3.29 E+2 g	Co-60	1.94 E-1		
		Eu-152	4.18 E-1		
2-4 inches	1.14 E+3 g	Co-60	1.59 E-1		
		Cs-137	3.62 E-2		
		Eu-152	6.41 E-1		
4-6 inches	7.53 E+2 g	Co-60	1.21 E-1	Co-60	<MDA
		Eu-152	3.70 E-1	Eu-152	<MDA
				Ba-133	2.60

* Most bioshield samples analyzed on-site were in a non-standard geometry. The results listed in this column are qualitative only unless otherwise indicated.

** Samples analyzed off-site were processed to produce samples that could be analyzed with a "standard" counting geometry. Results listed in this column are quantitative.

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Table 4-3

Bioshield Core Bore # 4

Three Feet Below the Reactor Core Mid-Plane - 45 degree Azimuth (-24 foot elevation)

Sample Depth	Sample Size	Nuclide Activity (pCi/g) On-Site Analysis *		Nuclide Activity (pCi/g) Off-Site Analysis **	
0-1.5 inches	5.17 E+2 g	Co-60	2.92 E-1	Co-60	1.43 E-1
		Eu-152	4.05 E-1	Eu-152	<MDA
				Ba-133	1.36 E+1
1.5-2 inches. First piece of solid core, but not good geometry	1.36 E+2 g	NNI			
2-2.5 inches. Second piece of solid core, good geometry	1.72 E+2 g	Eu-152	9.74 E-1		
		(results quantitative)			
2.5-3 inches. Third piece of solid core, good geometry	1.66 E+2 g	Eu-152	5.10 E-1		
		(results quantitative)			
3-3.5 inches. Fourth piece of solid core, good geometry	1.58 E+2 g	Co-60	5.24 E-1		
		Eu-152	1.82		
		(results quantitative)			
3.5-4 inches. Fifth piece of solid core, good geometry	1.83 E+2 g	Cs-137	2.78 E-1		
		(results quantitative)			
4-4.5 inches. Sixth piece of solid core, good geometry	2.01 E+2 g	Cs-137	1.74 E-1		
		Eu-152	6.94 E-1		
		(results quantitative)			
4.5-5 inches. Seventh piece of solid core, not good geometry	6.61 E+1 g	NNI			
5-5.5 inches. Eighth piece of solid core, good geometry	1.88 E+2 g	NNI			
5.5-6 inches. Ninth piece of solid core, good geometry	1.98 E+2 g	Cs-137	1.92 E-1		
		Eu-152	9.64 E-1		
		(results quantitative)			
6-6.5 inches. Tenth piece of solid core, not good geometry	6.51 E+1 g	Eu-152	1.25		
		Cm-245	1.31	NNI	

NNI=No nuclides identified

* Most bioshield samples analyzed on-site were in a non-standard geometry. The results listed in this column are qualitative only unless otherwise indicated.

** Samples analyzed off-site were processed to produce samples that could be analyzed with a "standard" counting geometry. Results listed in this column are quantitative.

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Table 4-4

Bioshield Core Bore # 5

Into Quad C wall drilled toward Quad B and into Monolith Around Thermal Column

Sample Depth	Sample Size	Nuclide Activity (pCi/g) On-Site Analysis	Nuclide Activity (pCi/g) Off-Site Analysis
0-1/2 inch. First sample from core, good geometry	1.12 E+2 g	Eu-152 5.63 E-1 (results quantitative)	NNI
About 31.5-32 inches. Last sample from core, good geometry	1.83 E+2 g	NNI	NNI

NNI=No nuclides identified

* Most bioshield samples analyzed on-site were in a non-standard geometry. The results listed in this column are qualitative only unless otherwise indicated.

** Samples analyzed off-site were processed to produce samples that could be analyzed with a "standard" counting geometry. Results listed in this column are quantitative.

4.2 Balance of Plant (BOP) Core Bore Results

The following tables show the results of direct beta measurements on the tops and bottoms of the ½ inch pucks cut from the BOP core bores. The direct activity measurement results shown in the tables are “net” beta activity. It is noted that the reported “net” activity results were obtained by subtracting the detector background response (cpm) due to cosmic and terrestrial gamma rays. Therefore, the “net” activity includes the beta contribution from natural radioactive constituents in concrete. The tables also show laboratory analysis results from portions of cores selected for individual radionuclide analysis.

Table 4-5

BOP Core Bore # 1 Reactor Building Quad A (Angled Core)

Sample #	Depth (in.)	Top/Bottom	Net Beta Activity (dpm/100cm ²)	On-Site Analysis (pCi/g)	Off-Site Analysis (pCi/g)
1	1.8	Top	364	NNI	
		Bottom	246	Cs-137 3.91 E-1	
2	2.3	Top	305		
		Bottom	15		
3	2.9	Top	282		
		Bottom	344		
4	3.4	Top	292		
		Bottom	0		
5	3.9	Top	85		
		Bottom	329		
6	4.2	Top	301		
		Bottom	-80		
7	4.8	Top	10		
		Bottom	59		
8	5.3	Top	129		
		Bottom	198		
9	5.8	Top	259		Co-60 5.86 E +0 Cs-137 5.89 E -1
		Bottom	168		
10	6.3	Top	298		Co-60 1.05 E +1 Cs-137 2.03 E +0
		Bottom	690		
11	7.5	Debris	N/A		Co-60 8.01 E +0 Cs-137 5.69 E +0

Notes:

1. NNI=No nuclides identified
2. Highlighted rows indicate core interaction with wall-floor joint.

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Table 4-6

BOP Core Bore #2
Reactor Building Quad C (Angled Core)

Sample #	Depth (in.)	Top/Bottom	Net Beta Activity (dpm/100cm ²)	On-Site Analysis (pCi /g)	Off-Site Analysis (pCi/g)
1	2.3	Top	482	Cs-137 2.30 E-1	Cs-137 5.12 E - 1
		Bottom	532	Cs-137 3.59 E-1	
2	2.8	Top	542		Cs-137 2.58 E - 1
		Bottom	409		
3	4.7	Debris	N/A		Co-60 4.36 E -1 Cs-137 3.04 E +0
4	6.6	Top	179		Cs-137 1.98 E -1
		Bottom	136		
5	7.2	Top	268		Co-60 4.36 E -1
		Bottom	151		
6	7.7	Top	89		NNI
		Bottom	315		
7	8.3	Top	245		
		Bottom	19		
8	8.8	Top	249		
		Bottom	118		

Notes:

1. NNI=No nuclides identified
2. Highlighted rows indicate core interaction with wall-floor joint.

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Table 4-7

BOP Core Bore # 3

Reactor Building Quad A (Horizontal into Wall)

Sample #	Depth (in.)	Top/Bottom	Net Beta Activity (dpm/100 cm ²)	On-Site Analysis (pCi/g)	Off-Site Analysis (pCi/g)
1	0.3	Top	556	Cs-137 1.02 E-1	H-3 5.99 E +0
		Bottom	286	NNI	
2	0.8	Top	-39		H-3 7.40 E +0
		Bottom	635		
3	1.7	Debris	N/A		
		Debris	N/A		
4	3.1	Top	99		H-3 5.61 E +0
		Bottom	146		

NNI=No nuclides identified

Table 4-8

BOP Core Bore # 5

Reactor Building Quad B (Into Wall)

Sample #	Depth (in.)	Top/Bottom	Net Beta Activity (dpm/100 cm ²)	On-Site Analysis (pCi/g)	Off-Site Analysis (pCi/g)
1	0.8	Top	123	Eu-152 5.63 E -1	
		Bottom	281	NNI	
2	1.3	Top	118		
		Bottom	236		
3	2.4	Top	212		
		Bottom	44		

NNI=No nuclides identified

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Table 4-9

BOP Core Bore # 7

Reactor Building (Lily Pad)

Sample #	Depth (in.)	Top/Bottom	Net Beta Activity (dpm/100 cm ²)	On-Site Analysis (pCi/g)	Off-Site Analysis (pCi/g)
1	0.3	Top	438	Co-60 4.46 E+0 Nb-94 3.06 E-1 Cs-137 5.90 E-1	H-3 <MDA
		Bottom	310	Co-60 2.14 E+0	
2	0.8	Top	153		H-3 <MDA
		Bottom	187		
3	1.4	Top	52		H-3 7.81 E+0
		Bottom	99		
4	2	Top	122		H-3 <MDA
		Bottom	245		
5	2.6	Top	0		H-3 5.80 E+0
		Bottom	118		
6	3.2	Top	-56		H-3 5.59 E+0
		Bottom	113		
7	3.8	Top	66		H-3 <MDA
		Bottom	249		

Table 4-10

BOP Core Bore #8

Reactor Building Canal E (Into Wall)

Sample #	Depth (in.)	Top/Bottom	Net Beta Activity (dpm/100cm ²)	On-Site Analysis (pCi/g)	Off-Site Analysis (pCi/g)
1	1.8	Top	546	NNI	H-3 <MDA
		Bottom	670	NNI	
2	2.4	Top	512		H-3 5.41 E+0
		Bottom	428		

NNI=No nuclides identified

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Table 4-11

BOP Core Bore # 9
Reactor Building-25 Ft. Pump Room Trench

Sample #	Depth (in.)	Top/Bottom	Net Beta Activity (dpm/100cm ²)	On-Site Analysis (pCi/g)	Off-Site Analysis (pCi/g)
1	0.3	Top	1,659,033	Co-60 9.63 E+1 Ag-108m 4.93 E+0 Cs-137 7.05 E+0 Eu-152 2.52 E+1 Eu-154 8.26 E+0	Co-60 3.64 E +1 Ag-108m 2.47 E +0 Cs-137 2.41 E +0 Eu-152 1.15 E +1 Eu-154 2.37 E +0 Eu-155 1.09 E +0 Sr-90 1.89 E +1
		Bottom	2,939	Co-60 5.34 E+1 Ag-108m 3.15 E+0 Cs-137 4.16 E+0 Eu-152 1.20 E+1 Eu-154 3.38 E+0	H-3 9.73 E +0
2	0.8	Top	148		Sr-90 1.13 E+0
		Bottom	345		H-3 7.08 E+0
3	1.4	Top	-10		
		Bottom	246		H-3 6.94 E+0
4	1.9	Top	473		
		Bottom	271		H-3 <MDA

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Table 4-12

BOP Core Bore # 10
Reactor Building Canal G (Angled Core)

Sample #	Depth (in.)	Top/Bottom	Net Beta Activity (dpm/100 cm ²)	On-Site Analysis (pCi/g)	Off-Site Analysis (pCi/g)
1	1.8	Top	143	NNI	
		Bottom	350	Cs-137 2.73 E-1	
2	2.3	Top	290		
		Bottom	369		
3	2.7	Top	249		Cs-137 6.65 E +0
		Bottom	207		
4	3.4	Top	240		Cs-137 9.75 E -1
		Bottom	207		
5	5.6	Debris	N/A		Co-60 3.05 E -1 Cs-137 2.81 E +0
6	7.8	Top	719		Cs-137 2.86 E -1
		Bottom	423		
7	8.4	Top	438		Cs-137 1.23 E +0
		Bottom	192		
8	9	Top	193		
		Bottom	160		
9	9.5	Top	212		
		Bottom	278		
10	10.1	Top	127		
		Bottom	235		

Notes:

1. NNI=No nuclides identified
2. Highlighted rows indicate core interaction with wall-floor joint.

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Table 4-13

BOP Core Bore # 11 Reactor Building Canal H (Angled Core)

Sample #	Depth (in.)	Top/Bottom	Net Beta Activity (dpm/100 cm ²)	On-Site Analysis (pCi/g)	Off-Site Analysis (pCi/g)
1	1.8	Top	389	NNI	
		Bottom	335	NNI	
2	2.3	Top	310		
		Bottom	418		
3	2.9	Top	198		
		Bottom	179		
4	3.4	Top	-56		
		Bottom	38		
5	4	Top	136		NNI
		Bottom	226		
6	4.6	Top	-47		Cs-137 1.10 E +0
		Bottom	80		
7	5.8	Top	9		NNI
		Bottom	212		
8	6.3	Top	226		
		Bottom	64		
9	6.9	Top	233		
		Bottom	177		
10	7.5	Top	267		
		Bottom	112		
11	8.1	Top	315		
		Bottom	147		
12	8.6	Top	371		
		Bottom	246		

Notes:

1. NNI=No nuclides identified
2. Highlighted rows indicate core interaction with wall-floor joint.

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Table 4-14

BOP Core Bore # 12
Reactor Building Canal G (Horizontal into Wall)

Sample #	Depth (in.)	Top/Bottom	Net Beta Activity (dpm/100 cm ²)	On-Site Analysis (pCi/g)	Off-Site Analysis (pCi/g)
1	0.3	Top	478	Cs-137 8.05 E-2	H-3 1.75 E +1
		Bottom	542	Co-60 2.72 E-1 U-235 4.82 E-1	
2	0.8	Top	197		H-3 1.90 E +1
		Bottom	153		
3	1.4	Top	-17		H-3 1.59 E +1
		Bottom	224		
4	1.9	Top	194		H-3 2.16 E +1
		Bottom	173		
5	2.5	Top	95		H-3 2.58 E +1
		Bottom	194		
6	3.1	Top	190		H-3 3.08 E +1
		Bottom	173		
7	3.6	Top	207		H-3 2.38 E +1
		Bottom	173		

Table 4-15

BOP Core Bore # 13
Reactor Building Canal H (Horizontal Into Wall)

Sample #	Depth (in.)	Top/Bottom	Net Beta Activity (dpm/100 cm ²)	On-Site Analysis (pCi/g)	Off-Site Analysis (pCi/g)
1	0.3	Top	49	NNI	H-3 8.17 E+0
		Bottom	187	NNI	
2	0.8	Top	20		H-3 <MDA
		Bottom	635		
3	1.4	Top	104		H-3 <MDA
		Bottom	188		
4	1.9	Top	287		H-3 <MDA
		Bottom	-146		

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Table 4-16

BOP Core Bore # 15
Primary Pump House

Sample #	Depth (in.)	Top/Bottom	Net Beta Activity (dpm/100 cm ²)	On-Site Analysis pCi/g	Off-Site Analysis pCi/g
1	0.3	Top	9743	NNI	H-3 5.77 E+0
		Bottom	241	Co-60 7.79 E-1	
2	0.8	Top	169		H-3 6.87 E+1
		Bottom	369		
3	1.4	Top	203		H-3 5.03 E+1
		Bottom	332		
4	2	Top	457		H-3 1.19 E+2
		Bottom	216		
5	2.6	Top	229		H-3 1.41 E+2
		Bottom	289		
6	3.2	Top	242		H-3 9.59 E+1
		Bottom	250		
7	3.8	Top	73		H-3 1.32 E+2
		Bottom	276		
8	4.3	Top	82		H-3 1.12 E+2
		Bottom	254		

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Table 4-17

BOP Core Bore # 16
Waste Handling Building

Sample #	Depth (in.)	Top/Bottom	Net Beta Activity (dpm/100 cm ²)	On-Site Analysis (pCi/g)	Off-Site Analysis (pCi/g)
1	0.3	Top	415,388	Co-60 8.47 E +1 Cs-137 2.72 E +4	Co-60 3.96 E +1 Cs-137 1.34 E +4
		Bottom	12,616	Co-60 5.34 E +1 Cs-137 1.86 E +4	Sr-90 9.89 E +2 H-3 4.60 E +1
2	0.8	Top	4,672		Sr-90 1.38 E +1
		Bottom	1,910		H-3 9.67 E +0
3	1.4	Top	518		Sr-90 4.35 E +0
		Bottom	129		H-3 5.52 E +0
4	2	Top	306		H-3 5.48 E +0
		Bottom	-4		
5	2.6	Top	621		H-3 5.36 E +0
		Bottom	720		
6	3.2	Top	-43		H-3 7.37 E +0
		Bottom	82		

Table 4-18

BOP Core Bore # 17
Cold Pipe Tunnel Trench

Sample #	Depth (in.)	Top/Bottom	Net Bet Activity (dpm/100cm ²)	On-Site Analysis (pCi/g)	Off-Site Analysis (pCi/g)
1	0.3	Top	694	NNI	
		Bottom	394	NNI	
2	0.8	Top	537		
		Bottom	118		
3	1.4	Top	30		
		Bottom	64		
4	1.9	Top	148		
		Bottom	241		
5	2.5	Top	0		
		Bottom	123		

NNI=No nuclides identified

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Table 4-19

BOP Core Bore # 18
Cold Pipe Tunnel

Sample #	Depth (in.)	Top/Bottom	Net Beta Activity (dpm/100 cm ²)	On-Site Analysis (pCi/g)	Off-Site Analysis (pCi/g)
1	0.3	Top	36,894	NNI	
		Bottom	3,136	NNI	
2	0.8	Top	458		
		Bottom	679		
3	1.4	Top	143		
		Bottom	-123		
4	2	Top	-39		
		Bottom	172		

NNI=No nuclides identified

Table 4-20

BOP Core Bore # 19
Fanhouse (-12 Ft.)

Sample #	Depth (in.)	Top/Bottom	Net Beta Activity (dpm/100 cm ²)	On-Site Analysis (pCi/g)	Off-Site Analysis (pCi/g)
1	0.3	Top	183,026	Cs-137 4.84 E +0	H-3 5.01 E +0
		Bottom	532	Co-60 3.59 E -1 Cs-137 2.96 E +0	
2	0.8	Top	259		H-3 <MDA
		Bottom	339		
3	1.4	Top	160		H-3 <MDA
		Bottom	259		
4	2	Top	374		H-3 <MDA
		Bottom	372		
5	2.6	Top	249		H-3 <MDA
		Bottom	146		

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Table 4-21

BOP Core Bore # 20
Hot Pipe Tunnel

Sample #	Depth (in.)	Top/Bottom	Net Beta Activity (dpm/100 cm ²)	On-Site Analysis (pCi/g)	Off-Site Analysis (pCi/g)
1	0.3	Top	1,525,563	Co-60 4.64 E +2 Cs-137 2.10 E +4	Co-60 4.00 E +2 Cs-137 1.82 E +4
		Bottom	902,213	Co-60 8.22 E +2 Cs-137 3.82 E +4	Sr-90 3.87 E +4 H-3 3.22 E +1
2	0.8	Top	679,926		Sr-90 4.05 E +4 H-3 7.62 E +2
		Bottom	272,635		
3	1.4	Top	166,827		Sr-90 6.40 E +3 H-3 1.30 E +2
		Bottom	88,449		
4	1.9	Top	73,518		H-3 6.67 E +1
		Bottom	37,650		
5	2.5	Top	35,394		H-3 3.73 E +1
		Bottom	21,930		
6	3.1	Top	22,003		H-3 3.02 E +1
		Bottom	14,741		
7	4.5	Top	6,533		H-3 2.23 E +1
		Bottom	2,954		
8	5	Top	1,959		H-3 4.21 E +1
		Bottom	1,482		
9	5.3	Top	483		H-3 1.44 E +1
		Bottom	362		
10	5.7	Top	302		H-3 9.49 E +0
		Bottom	65		

5.0 Evaluation and Conclusions

5.1 Bioshield Core Bores

The off-site analysis of the 0-12 in. sample from Core Bore #1 (-21 ft. elevation) showed Co-60 to be present at 3.39 pCi/g. The subsurface structural DCGL for Co-60 is 3.3 pCi/g. Eu-152 was also found to be present at 10.5 pCi/g, vs. its subsurface structural DCGL value of 9.4 pCi/g.

Barium-133 was found to be present at levels ranging from 2.38 pCi/g (19-23 in. inside the bioshield) to 65.7 pCi/g (first 12 inches of the bioshield). Both samples were from the -21 ft. core bore. As noted in the introduction, Ba-133 was not identified as a significant constituent of activated concrete when DCGLs were established for volumetrically contaminated building demolition rubble. However, a DCGL for Ba-133 will be no greater than that of Eu-152 (9.4 pCi/g) based on a comparison of their gamma decay schemes. Even without consideration of Ba-133, Co-60 results are sufficient to assess the ability of the bioshield to meet the applicable release criteria.

As described in the sampling plan for evaluation of bioshield activation (MWH05a), additional samples beyond the recommended initial samples may be required to accurately define the zone of activation that is above limiting DCGLs. Based on the results from the initial core bores, the present understanding of the activation status is summarized:

- 1) The annular concrete region of the bioshield at the core mid-plane (-21 ft. elevation) contains activation product concentrations in excess of nuclide-specific DCGLs from the inner surface to the steel liner at 24 in. thickness.
- 2) The zone of vertical activation of the annular bioshield concrete (> nuclide-specific DCGLs) extends as much as three feet above and below the core mid-plane. At the - 18 and - 24 ft elevations, detectable activity is observed at levels up to approximately 2/3 of a nuclide-specific DCGL, and the activity levels diminish with depth in concrete at these elevations.
- 3) The radial depth of activation beyond the 24 in. concrete bioshield, into the outer steel liner and beyond has not been confirmed as core drilling was not successful in obtaining sample material from the liner or the adjacent quad walls.
- 4) Core drilling to investigate activation in the Quad B shield concrete surrounding the Thermal Column did not penetrate far enough to obtain sample material sufficiently close to the Thermal Column.

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From these results and experience from other research and test reactors, a bioshield removal strategy is suggested:

- 1) The entire bioshield annular concrete from – 18 to -24 ft. should be removed for disposal as radioactive waste.
- 2) The bioshield outer steel liner and quad wall material from the elevations -18 to -21 ft. is to be staged for additional testing to evaluate the concentration of activation products against the respective DCGLs to determine the disposition of this material.
- 3) The potential zone of activation in the Quad B shield surrounding the thermal column may extend in the vertical direction beyond the -18 to -24 ft. region due to the large diameter of the Thermal Column (4 ft.). When the concrete removal plan is developed, provisions should be made to segregate the Quad B shield material from the region that encompasses two feet surrounding the Thermal Column (for testing).

5.2 Balance of Plant Cores

As stated in the Introduction, the primary objectives for the BOP cores are to determine the following aspects of concrete contamination:

1. depth of penetration via cracks and voids
2. soluble radionuclide penetration
3. radionuclide profiles.

Results of the present core bore sampling campaign are discussed for each of the listed objectives.

5.2.1 Depth of Penetration via Cracks and Voids

Table 5 -1 identifies the cores that were collected to investigate penetration of radioactive contaminants via cracks and voids.

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Table 5-1

Identification of Cores to Investigate Cracks and Voids

Core #	Location	Direction & Depth (inches)	Location Map	Photo (page)
1	Reactor Bldg. Quad A	Angled (8)	Figure 2	B-4
2	Reactor Bldg. Quad C	Angled (9)	Figure 2	B-5
10	Reactor Bldg. Canal G	Angled (10)	Figure 2	B-10
11	Reactor Bldg. Canal H	Angled (9)	Figure 2	B-11
19	Fan House – 12 ft. Floor	Vertical (3)	Figure 6	B-17
20	Hot Pipe Tunnel Floor	Vertical (6)	Figure 7	B-18, B-19

Cores 1, 2, 10 and 11 were collected for the purpose of investigating the “cold joints” between the floor and walls in the Reactor Building Quads and Canals. They were drilled into the walls at a nominal angle of 45 degrees from the vertical with drill entry at about 4 inches from the wall-floor interface. The cores intercepted the cold joint at a core depth of 5 to 6 inches. The distance into the wall-floor joint is typically about four inches from the floor-wall intersection. There was some variation in the depth to interception of the joint due to difficulty in controlling the drilling angle. Also, note that since the core-bore intersects the joint at an angle, several core pucks (or sub-samples) will typically contain portions of material from the floor-wall joint.

Refer to Tables 4-5, 4-6, 4-12 and 4-13 which show the results of activity measurements (surface activity and volumetric activity) versus depth for the four cores. The data rows covering the core bore regions that intercept the floor-wall joints are highlighted. Table 5-2 summarizes the activity trends of each of the four cores in the vicinity of the floor-wall joints.

Table 5-2

Core Bore Activity Trends at Wall-Floor Joints

Core #	Surface Beta Activity	Nuclide Activity Concentration
1	Significant increase at ~ 6 in.	Co-60 - peaks at 6 in. (5.9 pCi/g, >DCGL) Cs-137 - peaks at 7 in. (5.7 pCi/g, > DCGL)
2	Inconclusive – no significant peak	Co-60 – no discernable peak Cs-137 - peaks at 5 in. (3.0, > DCGL)
10	Distinct peak at ~ 7 in.	Co-60 – insufficient results Cs-137 – no distinct peak, but levels in excess of the DCGL from 3 to 6 in.
11	Inconclusive – no significant peak	Cs-137 activity is elevated at ~ 5 in. relative to adjacent pucks (1.1 PCi/g, 50% of DCGL)

From the information presented in Table 5-2, it is concluded that plant-derived radioactivity has penetrated into the wall-floor joints to some extent at all four of the locations investigated. Three of the cores exhibit activity in excess of nuclide-specific DCGLs at the joint. These are Core # 1 from Quad A, Core # 2 from Quad C and Core # 10 from Canal G. The fourth core, Core # 11, from Canal H, exhibits activity at 50% of a DCGL (Cs-137). None of these cores exhibit significant activity levels in the portions near the wall surface, i., e., > ~ 10% of DCGLs, so it is concluded that the primary path for contamination of the joints was via seepage through the joint from contaminated water in the surrounding Quads and Canals.

Cores 19 and 20 were located to span cracks in the floors of the Fan House and Hot Pipe Tunnel. This can be seen in the photos on pages B-17 through B-19. Activity verses depth data is presented in Tables 4-20 and 4-21. The results for Core # 19, while insufficient to draw a firm conclusion, suggest that the depth of penetration of activity beyond about the depth of the first puck (~ 0.5 in.) is small. On the other hand, Core # 20 shows depth of penetration of activity nearly to the end of the core (as evidenced by surface activity measurements). From the results of these two samples, it is not possible to determine if the presence of cracks played a significant role in the penetration of plant-derived radioactivity into the concrete. It appears more likely that the depth of penetration is more strongly correlated to the levels of activity in the water to which the concrete was exposed.

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5.2.2 Soluble Radionuclide Penetration

Several cores were drilled into the balance of plant structures to investigate penetration of radioactive contamination into intact concrete. Table 5-3 lists the cores. The results are summarized in Table 5-4. From examination of Table 5-4, it is seen that three indicators of depth of penetration are obtained. There are: direct surface activity measurements taken on puck surfaces, and radioassay of pucks for tritium, gamma emitters and other non-gamma emitters such as Sr-90.

Table 5-3

Identification of Cores to Investigate Soluble Radionuclide Penetration

Core #	Location	Core Direction & Depth (inches)	Location Map	Photo (page)
3 *	Reactor Bldg. Quad A Wall	Horizontal (3)	Figure 2	B-6
5	Reactor Bldg. Quad B Wall	Horizontal (3)	Figure 2	B-7
7	Reactor Building Elev. 0 (Lily Pad)	Vertical (4)	Figure 2	B-8
8 *	Reactor Bldg. Canal E Wall	Horizontal (3)	Figure 2	None
9 *	Reactor Building Pump Room Trench	Vertical (2.5)	Figure 2	B-9
12 *	Reactor Bldg. Canal G Wall	Horizontal (4)	Figure 2	B-12
13 *	Reactor Bldg. Canal H Wall	Horizontal (2)	Figure 2	B-13
15	Primary Pump House Room 4 Wall	Horizontal (5)	Figure 3	B-14
16	Waste Handling Building Evap. Rm. Floor	Vertical (3.5)	Figure 4	B-15
17	Cold Pipe Tunnel Floor Trench	Vertical (3)	Figure 5	B-16
18	Cold Pipe Tunnel Floor	Vertical (2.5)	Figure 5	B-16

* Designates locations where the concrete was frequently exposed to contaminated water during PBRF operation.

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Table 5-4

Radionuclide Penetration into Concrete - Summary of Measurement Results

Core # (location)	Net Beta	Tritium	Other Radionuclides
3 * Quad A wall	to ~ 1 in. depth	through entire core depth with maximum at ~ 1 in.	not analyzed
5 Quad B wall	low levels - inconclusive	not analyzed	only first puck analyzed - no significant activity
7 Lily Pad	to ~ 1 in., spotty thereafter	to ~ 3.5 in. but uneven, maximum at 1.5 in.	only first puck analyzed – Co-60 > DCGL
8 * Canal E wall	through entire core depth	uneven, but ~ 5 pCi/g at 2.5 in.	not analyzed
9 * - 25 ft pump room trench	to ~ ½ in., highly contaminated on core top, 2 nd puck low level	to ~ 2 in., maximum at ½ in.	Sr-90 to ~ 1 in. (2 nd puck) 1 st puck, Cs, Co, Eu all > DCGL (~ 10x)
12 * Canal G wall	to ~ ½ in.	through entire core depth, maximum at ~ 3 in.	only first puck analyzed – low levels of Co, Cs
13 * Canal H wall	low levels – penetrated to ~ 1 in.	to ~ 0.5 in, first puck only, < MDA thereafter	not analyzed
15 PPH, Rm. 4 wall	low levels through entire core depth	through entire core depth, maximum at ~ 2 ¾ in.	only first puck analyzed, Co-60 < 1 pCi/g
16 WHB Evap. Rm. floor	to ~ 3 in.	through entire core depth, maximum at ~ ½ in	To ~ 1.5 in (first three pucks analyzed), Co, Cs, Sr all > DCGL
17 CPT trench	to ~ 1 in., low levels	not analyzed	only first puck analyzed, none > MDA
18 CPT floor	to about 1 in, most activity on core surface	not analyzed	only first puck analyzed, none > MDA

* Designates locations where the concrete was frequently exposed to contaminated water during PBRF operation

Tritium analysis was conducted on nine of the eleven cores shown in tables 5-3 and 5-4. Of the nine cores analyzed, four cores showed tritium penetration

throughout the core length, up to 4 in. in depth and one additional core showed penetration to within $\frac{1}{2}$ in. of the full core length. The five locations of deep tritium core penetration are: Quad A wall (#3), -25 ft. Pump Room trench (#9), Canal G wall (#12), Primary Pump House wall (#15) and the Waste Handling Building Evaporator room floor (#16). Among the five cores showing deep penetration of tritium, only cores # 3, 9 and 12 are from locations where the concrete was believed to have been consistently exposed to process water.

In none of the cores analyzed did tritium exceed the DCGL of 166 pCi/g. The highest concentrations were measured in the core collected from the Primary Pump House wall (#15). The maximum measured concentration was 141 pCi/g. In the other cores with positive tritium results, typical tritium concentrations are between 5 and 20 pCi/g.

The other radionuclides measured in BOP concrete samples include Co-60, Cs-137 and Sr-90. Of these, Cs-137 is generally the most mobile, followed by Sr-90 with Co-60 being the least mobile in concrete exposed to contaminated process water. Only a limited number of the BOP cores were analyzed for all three of the radionuclides, Co-60, Cs-137 and Sr-90 so only limited information of the depth of penetration of the individual radionuclides was obtained. However by examining the net beta surface activity depth profile data, some idea of their depth of penetration can be obtained, as all three radionuclides are beta emitters (Cs-137 and Co-60 are beta-gamma emitters and Sr-90, a beta emitter).

From the summary presented in Table 5-4, it is concluded that the depth of penetration of the primary beta emitting radionuclides is limited to about one inch or less in the cores where significant activity levels are observed on the core top surface. Only cores # 9 (-25 ft. pump room trench) and #16 (WHB Evap. Room floor) exhibit this characteristic. Cores # 19 and # 20 are excluded from this discussion as they are from fractured concrete – the presumption being that the radionuclide penetration in these cores is driven by flow of contaminated water through fractures.

5.2.3 Radionuclide Profiles in Balance of Plant Concrete

Only a limited number of balance of plant cores contained sufficient activity for the suite of laboratory analysis necessary to evaluate radionuclide profiles in the balance of plant concrete. Three cores were identified as suitable candidates - those with surface beta activity $> 200,000$ dpm/100-cm². The core top-end aliquots (pucks) were sent to the off-site vendor laboratory for analysis for tritium, gamma emitters and Sr-90. Table 5-5 presents the analytical results for the selected cores. Activity ratios for radionuclides (individual radionuclide activity to total activity) at each core location were calculated and these are shown in Table 5-6. Though not shown in the table, uncertainties were calculated for the activity ratios and the uncertainties (one standard deviation) are $\pm 50\%$. Thus, the

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95% confidence intervals for the individual activity ratios are approximately the ratio $\pm 100\%$. This uncertainty is based on analytical uncertainty only – it does not consider the added uncertainties due to sampling and sample handling errors.

From Table 5-6, it is seen that Co-60 and Sr-90 predominate in the Reactor Building core; the Cs-137/Co-60 activity ratio is only 0.07. However in the WHB and Hot Pipe Tunnel cores, the Cs-137/Co-60 ratios are 338 and 45.5 for the WHB and Hot Pipe Tunnel cores respectively.

Table 5-5

Activity Concentrations in Samples Selected for Radionuclide Profile Evaluation
(pCi/g)

Core #	Location	H-3	Ag-108m	Co-60	Cs-137	Eu-152	Eu-154	Eu-155	Sr-90
9	- 25 ft pump room trench	9.73	2.47	36.4	2.41	11.5	2.37	1.09	18.9
16	WHB Evap. Rm. floor	46		39.6	13400				989
20	Hot Pipe Tunnel	32.2		400	18200				38700

Table 5-5 note. Blank cells indicate that the radionuclide was not detected or was < MDA.

Table 5-6

Radionuclide Activity Ratios in BOP Core Samples

Core #	Location	H-3	Ag-108m	Co-60	Cs-137	Eu-152	Eu-154	Eu-155	Sr-90
9	- 25 ft pump room trench	0.115	0.029	0.429	0.028	0.136	0.028	0.013	0.223
16	WHB Evap. Rm. floor	0.003		0.003	0.926				0.068
20	Hot Pipe Tunnel	0.001		0.007	0.317				0.675

6.0 References

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